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ABSTRACT

With the dawning of the Information Age and the era of global competitiveness, new demands have been brought to universities to find ways of conducting basic research, of educating engineering students, and of interacting with government and industry. This paper describes an initiative that was created in Rochester, New York, an important center of imaging and image science for more than a century. The guiding vision of this Center for Electronic Imaging Systems (CEIS) is to establish and maintain a leading national center for all phases of electronic imaging systems and for the education of world-class scholars to lead imaging science into the 21st century. The paper describes the fundamental principles upon which the CEIS was founded, the management structure of the Center, new approaches to engineering education within the Center, and the emphasis on research and technology transfer. The hallmark Research Triplet concept is described as are main research themes and interactions. (Contains 19 references.) (Author/ASK)

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The Center for Electronic Imaging Systems: Imaging in the Information Age

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Abstract - *With the dawning of the Information Age and the era of global competitiveness, new demands have been brought to universities to find ways of conducting basic research, of educating engineering students, and of interacting with government and industry. In this paper we describe an initiative that was created in Rochester, New York, an important center of imaging and image science for more than a century. The guiding vision of this Center for Electronic Imaging Systems (CEIS) is to establish and maintain a leading national center for all phases of electronic imaging systems and for the education of world-class scholars to lead imaging science into the 21st century. We describe the fundamental principles upon which the CEIS was founded, the management structure of the Center, new approaches to engineering education within the Center, and the emphasis on research and technology transfer. The hallmark Research Triplet concept is described as are main research themes and interactions.*

Introduction

The information age has developed from society's need for improved communication, documentation, and entertainment. Today the field of electronic imaging is emerging from this age as the brightest prospect for remarkable technological advances and for substantial economic growth through improved global competitiveness in an ever more decentralized world. During the next two decades the field of electronic imaging will undergo a continuation of remarkable evolution and growth. Both in technology and in products for the marketplace, the importance of electronic imaging as part of the information superhighway cannot be overemphasized. In *Being Digital* Nicholas Negroponte, the visionary director of MIT's Media Lab, states that "The information superhighway may be mostly hype today, but it is an understatement about tomorrow. It will exist beyond people's wildest predictions."[1] Universities, corporations, and government must begin now to adapt to the inevitable changes being experienced today and expected in far greater measure in the near future.

In light of this new technological, scientific and economic environment, the challenge for universities and corporations in the United States is to find new approaches to basic research and collaboration with industry that maximize results from the expenditure of research dollars; involve university, industry and government in a cooperative and productive alliance; speed the technology transfer process to increase economic competitiveness; ensure the relevance of work done; and to educate the "best and brightest" to become the scientists who carry the information age forward. The university must expand its traditional role as provider of talent to industry and become a more active partner in technology transfer and economic growth.[2,3] Technology transfer, the movement of technology from where it is generated to where it is used [4], is an evolving concept. The nation's universities have long engaged in basic research, and the nation's corporations have looked within that body of work to find information they can use. But with resources declining and the need for societal relevance, the results required from technology transfer have increased and broadened. "As a process, technology transfer suffers the burden of great expectations."[5]

New trends are evolving in education and in university/industry relations and young scholars need education, encouragement, and a smoother transition into industrial research. In an effort to answer these challenges, CEIS was formed. The Center is a consortium merging the University of Rochester and the Rochester Institute of Technology with industry partners including Eastman Kodak and Xerox Corporation and major funding agencies such as the National Science Foundation and the New York State Science and Technology Foundation, Fig. 1.

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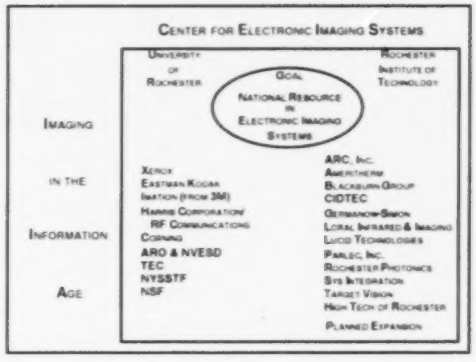

Figure 1. The Center for Electronic Imaging Systems is composed of a number of university, industry, and government partners. Current members are shown.

Beginning in the late 1980s, a group of Rochester area technical leaders from industry and academia began discussions of possible cooperative efforts in science and engineering. The vision of this informal group, which became known as the Rochester Imaging Consortium, was to establish in this geographical area a world class center for electronic imaging. The concept was to build on the strong historical foundation of imaging expertise in the region, and to establish a basis for leadership in this economically important, emerging field. One of the first tangible outcomes from the Rochester Imaging Consortium was the successful proposal for establishment of an S/IUCRC in Electronic Imaging Systems. The University of Rochester and the Rochester Institute of Technology were selected by the National Science Foundation in 1992 to establish this academic center of excellence based on a policy of strong interactions with industrial partners including initially Eastman Kodak, Xerox, Harris/RF Communications and 3M Company. Since 1992 as a continued realization of the vision of the Rochester Imaging Consortium, CEIS was formed to include a Center for Advanced Technology in Electronic Imaging Systems (CAT-EIS) sponsored by the New York State Science and Technology Foundation as well as the S/IUCRC and other related activities. The CEIS organization provides powerful leveraging of its member components through business support, outreach, and technology transfer activities. The continuing role of CEIS is threefold: 1) contribution of basic research with an emphasis on relevance, 2) contributions to an integrated educational program, and 3) contributions to industrial and economic growth. The University of Rochester and the Rochester Institute of Technology have made impressive strides toward the establishment of the CEIS as a leading academic research center. CEIS continues to stress development of educational programs that include innovative strategic alliances with engineering, business, and science schools to educate the future leaders in the field of electronic imaging.

The Technology

The field of electronic imaging is a rapidly emerging discipline involved in the capture and recording of an image as well as in the storage, coding, enhancement, retrieval and reproduction of images. It includes the areas of telecommunications, distribution, printing, and display. Among the academic disciplines in this field are imaging science, photonics, electrical engineering, computer science, and solid state physics. Advances in these fields will lead to important new systems for factory automation, communications, office automation, consumer imaging, medical diagnostics, and defense.

With the arrival and continuing growth of the information age it is clear that the field of electronic imaging is a bright prospect economically and a most challenging topic technologically. Therefore electronic imaging was chosen to be the focal point of our attempt to create a new and more productive way of linking university research with the sources of government funding and the needs of national industry.

Vision Statement

The guiding vision for the Center for Electronic Imaging Systems is to establish and maintain a leading national center for all phases of electronic imaging systems emphasizing pre-competitive, high-payoff research and the education of world-class scholars to lead imaging science into the 21st century.

Creating A New Alliance

The basis for this new alliance was formed in 1987 when The Institute of Optics of the University of Rochester was designated a Center-of-Excellence under the U.S. Army University Research Initiative (ARO-URI) Program [6]. Block funding for the ARO-URI Center was awarded to the University of Rochester as a result of a proposal competition with 43 other universities. The strategic plan was drawn around relating the basic research effort of the entire faculty of The Institute of Optics [7] to important central thrusts in optoelectronics. The close knit optics faculty already formed an exceptionally strong team ideally suited for a program that was designed "for the faculty by the faculty." Funding established the Center for Opto-Electronic Systems Research which focused on contributing basic scientific knowledge in signal and image processing and photonics and on conducting significant technology interactions with designated Army laboratories. This URI initiative also contained a far-sighted fellowship program ($1 million per year) for attracting and educating the most promising young scholars in optoelectronics to the University of

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Rochester. Twenty doctoral scholars were funded for their entire course of study. After a second review process this Center was redesignated until the year 1997.

In the late eighties Nicholas George and colleagues from the university and industry communities joined in forming the Rochester Imaging Consortium. This group included industry leaders from the Eastman Kodak Company and from Xerox Corporation whose vision was (and remains) to continue the Rochester community as a world leader in imaging. Four people who contributed greatly to the high level vision of the Rochester Imaging Consortium were Gary H. Conners and Edwin P. Przybylowicz, at that time with Eastman Kodak, Mark B. Myers of Xerox, and Rodney Shaw of the Rochester Institute of Technology. Faculty from the University of Rochester and the Rochester Institute of Technology embarked upon this alliance with the goal of building systematically on the field of electronic imaging to produce significant, relevant basic research and to devise some innovative management strategies that would work across diverse university and corporate boundaries to expedite the transfer of technology and foster economic development. [8] At the same time, Professor Rodney Shaw, then Director of the Center for Imaging Science at RIT, was leading the establishment of the first PhD program in the United States devoted to the study of imaging.

For a number of years, leaders in the Rochester industry and university communities and in major Army laboratories had been expressing the need for improved cooperation and interaction and for leveraging research and development activities. At a meeting of the Physics Directorate of the Army Research Office in 1989, Dr. Gerald Iafrate stressed to Nicholas George and B.D. Guenther, Director of the ARO Physics Directorate, the need for improved cooperation and interaction and for leveraging of ARO-URI research by obtaining support from industrial leaders in electronic imaging.

At the same time other state and federal funding agencies had recognized the need for improved interaction between laboratories, universities, corporations, and government. The National Science Foundation developed a large number of highly successful centers in many fields of science and engineering. [9] Of particular interest to the Rochester Imaging Consortium was the NSF State/Industry/University Cooperative Research Center (S/IUCRC) program. In this program Center designation requires major funding participation committed for a period of four years by industry (a minimum of four corporations), the New York State Science and Technology Foundation (NYSSTF), and the Directorate of the National Science Foundation. Eastman Kodak Company (Dr. Edwin Przybylowicz) and Xerox Corporation (Dr. Mark Myers) graciously funded an eighteen-month proposal effort that culminated in the designation of the Center for Electronic Imaging Systems as a center of excellence in the field of electronic imaging. In the United States there are more than fifteen designated S/IUCRC Centers. The interested reader can find mission and rationale statements in an official bulletin from the National Science Foundation. [9]

As to the rationale for building an initiative in electronic imaging in Rochester, in remarks at the first site visit by the National Science Foundation, Nicholas George stated: "The entire Rochester technical community is unique in its dedication to imaging. Tracing at least to George Eastman and the Eastman Kodak Company and including a virtual army of leading engineers and scientists at a host of corporations, Rochester continues to be consistent in this commitment. Certainly one marvels at the teaming of Chester Carlson and Joseph Wilson and their efforts to build the Xerox Corporation. The flowering of the University of Rochester and the Rochester Institute of Technology has been due in large part to this community spirit for science and technology. So as the Information Age [10] spawned major initiatives throughout the world, it was natural that Rochester would strive to contribute to 'Imaging in the Information Age,' the mantra of the Center for Electronic Imaging Systems."

Since joint ventures between dissimilar organizations often merge people and cultures having different expectations and incentives, a framework for this partnership was created that included principles to encourage and foster a workable, sustainable basis for cooperation and respect among institutions and among the individual participants as well. Rosabeth Kantor's study of strategic alliances, *When Giants Learn to Dance* [11], describes five requirements for successful consortia or strategic alliances. These points are detailed with respect to the Center for Electronic Imaging Systems.

1. Success of the alliance must be important to senior management of all the participating organizations.
2. A formal agreement must define the distribution of rewards for all participants.
3. Continuing interdependence must exist among participants for the life of the consortium.
4. The consortium must contain a mechanism to insure that information flows between participants.
5. There must be occasions for participants to get together informally to build trust.

Operation of the Center

Management Structure

The management structure of the Center is a matrix organization since faculty, doctoral scholars, and

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corporate engineers and scientists are drawn from separate universities and member corporations. Primary to the philosophy of our organization is a team approach to management. The Center Director is Dr. Nicholas George. The Associate Director at the University of Rochester is Dr. Michael A. Kriss who also manages the Center for Optoelectronics and Imaging facility at the South Campus. Associate Directors at the Rochester Institute of Technology are Dr. Gary H. Conners, Associate Provost for Outreach Programs, and Dr. Ian Gatley, Director of the Center for Imaging Science at RIT.

The management team governs the four major Center divisions (Fig. 2): research, technology, business, and outreach. Those wishing more information on all aspects of the Center are invited to visit our award-winning web site at www.ceis.rochester.edu.

CENTER FOR ELECTRONIC IMAGING SYSTEMS MAJOR DIVISIONS			
RESEARCH	TECHNOLOGY	BUSINESS	OUTREACH
RP	TIG	BIT	EIF

Fig. 2 Management structure of the Center for Electronic Imaging Systems

In facing the challenge of making our total research and technology transfer output and relevance greater than the sum of the individuals' output, we have employed many of the management ideas developed by the late W. Edward Deming in his Total Quality Management philosophy of action. Our unique Research Triplet concept, described below, stresses a team approach to research, coupling university and corporate scientists in a partnership at all levels in the research process. Corporate and government sponsors are considered "customers" of CEIS, and customer satisfaction is a central priority. We also believe, as Deming proposed, that a creative environment is necessary to foster innovation. Our unique facilities, Special Interest Groups, and workshops were instituted to encourage an open, cooperative, and interactive environment for our participants.[12,13,14]

Industrial Advisory Board (IAB)

The Industrial Advisory Board is formed of corporate managers acting as a corporate board of directors for the Center. They meet twice yearly and they exert strong management influence at the strategic level. The early success of CEIS was due in large part to the management experience and vision of Drs. Mark Myers, Keith Knox, Steve Bolte, Michael A. Kriss, Gary Bottger, Paul Roetling and Vincent Piarulli. Past IAB Chair Dr. Gary Bottger of Eastman Kodak has contributed great management skill to our program as has current Chair Ms. Mary Ann Dvonch of Xerox.

University Policy Committee (UPC)

Parallel to the IAB is the University Policy Committee. Together with other high level administrators of both universities, this group provides governance for the Center. Members include Vice Provost Gary Conners and Dean Robert Clark of the Rochester Institute of Technology and Dean Thomas J. LeBlanc and Dean Kevin Parker of the University of Rochester.

Education

Education and education outreach are administered directly by the director's office working with outreach personnel. All of the core university research leaders are members of the teaching faculty. Typically each faculty person lectures 3 hours per week during the fall and spring semesters. This schedule often includes one graduate course and one undergraduate course. Hence, there is a built-in integration of research into the teaching program. In American research universities this is the general pattern, and it has served us well.

General trends of improving engineering education and the evolving roles of academia, industry, and government are reported by President Charles M. Vest of the Massachusetts Institute of Technology [15]. Specific methods for moving emphasis on problem solving into undergraduate courses in many fields are illustrated by Eric Mazur [16] and in the fascinating book "The Fermi Solution," by H.C. von Baeyer [17].

CEIS Undergraduate Efforts

The Center for Electronic Imaging Systems (CEIS) strives also to diffuse its new findings in electronic imaging into the undergraduate curriculum. There are two main aspects to this. One is a program funded in part by the U.S. National Science Foundation called "Research for Engineering Undergraduates." In this program special fellowship money is provided to fund "honors projects" where a senior undergraduate conducts research within the laboratory environment of a professor. Secondly, related efforts are being made by CEIS to start new interdisciplinary courses such as "Image Science," "Digital Video," and "Digital Image Processing" that are specially designed for freshmen and sophomores.

A group of graduate students at the University of Rochester, including students from the United States

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and around the world, was polled regarding the value of doing research as an undergraduate. Among students from the USA, more than 75 percent had undertaken some form of undergraduate research. One said that "It was the most valuable and inspiring experience that I have had as an undergraduate."

The importance of undergraduate research experience cannot be over emphasized. To illustrate this point, we report further on the opinions registered by the graduate student group. The following remarks are paraphrased slightly from their comments. "While coursework is obviously of key importance, it is independent research which shapes the raw facts into usable tools. A degree is of questionable merit if a student graduates without the resources to apply the knowledge he or she has gained. It is research experience that serves to smooth the transition from the 'cookbook' nature of student labs to the more demanding realm of professional research. To meet his goal, a successful program for undergraduate independent research will meet the following four criteria: 1) it will complement the student's academic education; 2) it will bring the student into contact with professionals in his or her chosen field; 3) it will help the student define career goals; and 4) it will affirm the value of the student's undergraduate education. By incorporating these four features an undergraduate research program will greatly smooth the student's transition from the undergraduate to the professional level. During the course of designing, implementing, and analyzing original work, the student will hone reasoning abilities, develop communication skills, and gain a clearer career focus. By completing the project, the student will be rewarded with both self-confidence and a stronger resume. It is clear that research experience combined with classroom schooling gives the student the resources needed to apply education to a wide range of problems. Without it, the student has received only half an education."

Research

Stimulated by federal and state programs, universities are playing a significant role in increasing the competitiveness of American industry through the more rapid transfer of technology among university, industrial, and defense sectors. "Competitiveness would benefit greatly from a national program aimed at greatly increasing the flow of university faculty and industrial scientists and engineers in and out of each other's institutions."[18] With this philosophy in mind, we have found that a three-stage process works best for our technology transfer efforts. The first stage consists a series of meetings to meld Center research areas with the realistic needs of the various corporate laboratories as determined by corporate researchers and scientific administrators. "The first step in enabling universities and companies to overcome problems in a productive relationship may be for the company R & D managers to identify technological areas they want to pursue. This is the opposite of the current trend where industry visits universities looking for technology."[19] The second stage consists of a series of workshops offered to our industrial partners during which faculty present research findings and areas of continuing interest which are relevant to the predetermined target areas. The third stage consists of setting up working research visits where faculty, postdoctoral scholars, and doctoral candidates spend considerable working time at a partner's laboratory to accomplish meaningful joint research.

Research Triplets

A key element in our technology transfer program is the direct involvement of industrial scientists and engineers in the research effort, the third of the stages described above. This linking of people from industry and university into a cohesive team is the unique **Research Triplet** concept which has become a hallmark of CEIS. "If technology is to be transferred to the benefit of both institutions [industry and university], they must be inextricably entwined into a system wherein each can function independently, but function together for full technology transfer effectiveness, each supporting the other in an effective feedback system."[4] Each triplet consists of a faculty investigator, a postdoctoral scholar (or research fellow), and an engineering/scientist from a member corporation, all working together on a particular research topic determined as described above, Fig. 3. Since it is our belief that technology is transferred by people, not paper, Research Triplet groups hold frequent sessions to pursue their chosen line of research. At weekly or biweekly meetings, the Research Triplet group meets to review work accomplished, trade ideas, and direct the activities of the postdoctoral fellow for the next working period. To date over 30 of these research triplets have been established in 9 research theme areas of electronic imaging (themes and triplets are described below), and others are in the formation process. The formation and linking of Research Triplets

A NEW MODE FOR COOPERATIVE RESEARCH

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Figure 3. A new mode for cooperative research, the Research Triplet couples a faculty principal, an industrial principal, and a post doctoral or PhD fellow working on a topic of mutual interest in one of 9 theme areas.

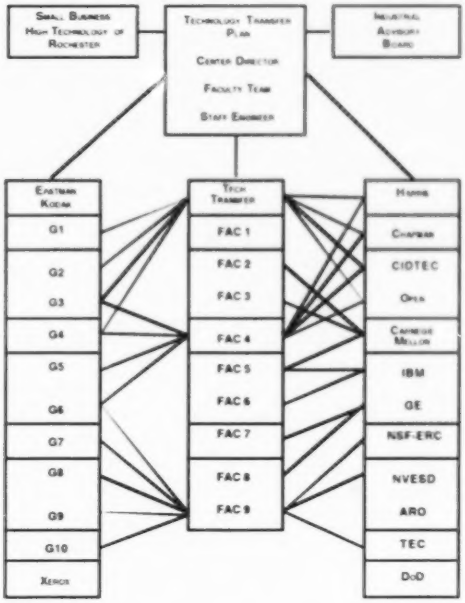

Fig. 4. Research Triplet teams depend on effective personal interaction among the researchers involved. These interactions cannot be predicted ahead of time, but develop in a way similar to a neural network.

depend on effective personal interaction among the researchers involved, and maintenance of productive triplets is crucial to a successful technology transfer program. Yet such teams cannot be mandated from above; they must develop from mutual interest and respect among team members. The activities of these triplets are designed along the lines of a professional society, and support such as a newsletter, special interest group meetings, bimonthly workshops, and tutorials are included in the framework to foster a relaxed and open environment which leads to a free exchange of ideas and increasingly better working and personal relationships. As shown in Fig. 4 these interactions are similar to a neural network in which the exact connections or weights cannot be predicted ahead of time; but with proper guidance and a good environment, the elements arrange themselves to provide the desired output.

Themes

In the establishment of the major thrusts of the research program, the faculty founders worked closely with the Industrial Advisory Board and important guidelines as to project selection were established. Careful fit to the programs of our corporate sponsors was planned and maintained. From the corporate point of view, the high-level consideration is to align the core research with strategic topics called themes. These themes or systems goals were established (in 1992) and additions, deletions, or changes require the approval of the IAB. The Center Director and management team are careful that funded projects "fit" and are appropriate to the selected themes. The faculty and corporate engineering scientists cooperate in the origin and selection of specific projects. The current themes which form the basis for our S/IUCRC core research program have been in place from the inception of the Center, with the exception of Optomechatronics which was added in 1994. The current themes are described as follows:

1. Electronic Imaging Systems Analysis
2. Sequences of Images
3. Image
4. Image Processing
5. Color
6. Imaging Through Turbulence
7. Automatic Pattern Recognition
8. Visualization & 3-D Display
9. Optomechatronics.

It is intended that Themes will have a long "time constant," typically remaining unchanged for 4 or 5 years. When changes in Themes are made, it will be done only in consultation with the Industrial Advisory Board of CEIS. It is also intended that these themes span a broad range of technology, representing the total "imaging chain," here referring to all of the subsystems involved in an image information system ranging from image capture to hard copy output or soft display.

Within each research Theme area, there will be several Research Projects. Individual projects are intended to have a shorter time constant than the Themes, typically lasting 18 months to 2 years. Wherever possible, S/IUCRC Research Projects will be conducted in the "Triplet" mode. By definition, this means that every project will involve three classes of participants: one or more faculty researchers, one or more industrial researchers, and one or more doctoral or post-doctoral fellows.

Vision For The Future

Our vision for the Center for Electronic Imaging Systems continues to be to establish and maintain a leading national center for research, industry and education in all phases of electronic imaging systems by joining universities with industrial leaders and small businesses. Acting on a belief that the university should become a critical participant in today's changing

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technology and a contributor to local, state and national economic growth, we devised a creative alliance of university, industry, and government that addresses the issues of global competitiveness, more efficient technology transfer, innovative education methods, and optimized use of research funding within the university. We do not manage or control the creative aspects of research; we provide systems that support creative research and provide an appropriate atmosphere for cooperation. The Center is committed to outreach to industry with interactively planned projects of strategic importance and to nurturing small and emerging companies in electronic imaging. The Center continues to stress development of graduate-level educational programs that include innovative strategic alliances with engineering, business, and science schools to educate the future leaders in the field of electronic imaging. The Center seeks creative solutions to problems in the rapidly changing arenas of university research, government and industry sponsorship of research, and technology transfer to large and small businesses in electronic imaging.

Acknowledgment

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